Designing for the Ubiquitous Computing era: towards the reinvention of everyday objects and the creation of new user experiences.

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ABSTRACT. *Researchers of the Ubiquitous Computing community (Ubicomp) have been pursuing the vision of a world where technologies and services permeates every object of our lives for years. With components getting smaller, cheaper and more powerful, it has become possible to manufacture connected objects capable of interacting with resources of the World Wide Web. This opens up the possibility for researchers and practitioners to consider information as a design material and objects as platforms for services. By allowing users to personalize, complement or repurpose the functions of their objects, such services have a great impact on the way artifacts are designed. Designing for the Ubiquitous Era requires modifying our practice and reinforcing collaboration between disciplines at every steps of the creation process. In this article, we discuss the need to reinvent objects and to investigate the tools supporting the creation of engaging user experiences.*

KEYWORDS: Ubiquitous Computing, design research, interaction design, product design, user experience design, connected objects, smart objects, object-based services, web of things.

1. Introduction

In the early 90's, Xerox PARC researcher Mark Weiser envisioned a new computing paradigm where information services are not processed and delivered by personal computers but by a variety of devices proliferating in the environment. In a foundational paper entitled "The computer of the 21th century" [Weiser, 1995], he described the possible future relationships between people, practice, and technology of the Ubiquitous Computing (Ubicomp) era. Often referred to as the pervasive penetration of everyday life with computing technologies, this influential vision led researchers to explore the interaction of computing through physical objects rather than general-purpose computers (i.e. physical computing), the ability of environments to sense and respond to the presence of people in an intelligent way (i.e. ambient intelligence) and the opportunity to digitally identify or augment physical objects with information or services (i.e. the Internet of things).

If embodying the UbiComp approach in people's everyday life has been an obstacle for a long time, the exponential growth and the inexpensiveness of computing capabilities (as described by Moore's law), the miniaturization of electronic components and the democratization of wireless networking infrastructures today allow not only lab researchers but also manufacturers to embed connectivity chipsets, tiny web servers and microcontrollers into everyday objects. Products as the Roomba[1] robotic vacuum cleaner, the Nabaztag[2] smart companion or the Ambient Orb[3] light illustrated the feasibility of creating augmented objects that do not look like traditional computers, as depicted in figure 1. The borders between the "white goods" (i.e. appliances) and "brown goods" (i.e. consumer electronics) have then started to shade, while objects' value tended to shift from mediums to data with the democratization of "software as a service" (SaaS) [Turner, Budgen, et Brereton, 2003] and "cloud computing" technologies [Buyya, Yeo, et Venugopal, 2008].

Since the establishment of the World Wide Web as a platform of services with considerable social and commercial benefits, end-users are moreover looking for new ways to access information anywhere, anytime. In the same way they embraced the instantiations of Web services as mobile applications, they are likely to want to consume data on new connected objects that can be considered as services "avatars" (i.e. a physical artifact embodying a specific facet of a Web service). According to User Experience designer Mike Kuniavsky, "information no longer needs to be the purpose of an object, but one of many qualities that enables it to be useful and desirable in ways that are more directly related to people's wants and needs" [Kuniavsky, 2010 44]. The design of objects is therefore no longer restricted to form, function, material and production, it should considerate objects as platforms for experiences, services or activities [Buchanan, 2001], whose functionality are offered or enhanced by the services they instantiate.

In this article, we propose to study the change brought about by the computational and connectivity capabilities of objects and to highlight the need for defining a new design practice. In a first part, we discuss the way the Ubicomp community acknowledged the need of considering user experience design in their research and show that the re-design of objects constitutes a novel challenge. In a second part, we illustrate the new capabilities of objects and identify the different types of services that can be built on top of them. In a third

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[1] Designed by iRobot. http://www.irobot.com

[2] Today sold under the name « Karotz ». http://www.karotz.com/

[3] Designed by Ambient Devices. http://www.ambientdevices.com/

part, we highlight the pragmatic issues brought by services and discuss their implications in the design of connected objects. We finally present the design strategy that led a small team of product and service designers to collaborate in order to explore the impact of connected objects on form, users' perception and service's experiences.

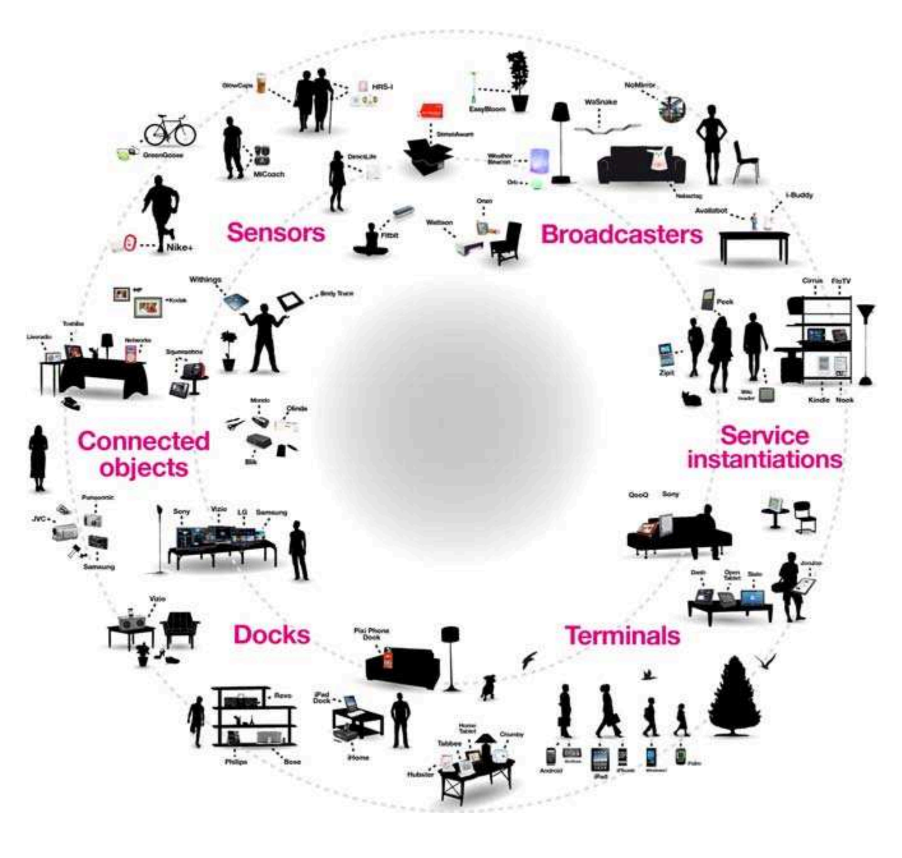

Figure 1. A market-based map of connected objects.

2. From a technological-driven research to a user-centered research in Ubicomp

As stated by Bell and Dourish, Ubicomp has always been an unusual research area. Unlike other computer science topics building upon past results, it is not driven by "the problems of the past but by the possibilities of the future" [Bell et Dourish, 2007]. Although researchers have been pursuing Weiser's vision and developed their agenda to anticipate future trends and meet future needs, their practice is often conceived as being primarily driven by technology. Based on a literature review, we propose in this part to retrace the way Ubicomp has been explored by researchers among the past decades and discuss the shift from a technological-driven research to a user-centered research. We then discuss the role of designers in the creation of connected objects.

2.1. User needs, user experience and artifact design in Ubicomp literature

By analyzing the thinking that underlies Weiser's vision from a phenomenological perspective, Araya first stressed out the need for studying the transformations brought by this “emerging form of technological absolutism” on people’s perception of the world [Araya, 1995]. This critical philosophical analysis led researchers as Edwards and Grinter to open up the discussion about the technical, social and pragmatic issues of Ubicomp technologies in homes such as reliability, administration and interoperability with researchers of various disciplines [Edwards et Grinter, 2001]. Bohn et al. more recently broaden the scope by exploring the social, economic and ethical implications of living in a world with connected objects [Bohn et al., 2004]. They especially examined, with regards to the potential business models, the privacy and control delegation issues that could lead users to reject such artifacts.

Even if predicting the future is difficult, these discussions reflect the needs for designers to balance the desire of technological capabilities with existing lifestyles and acceptable practices. This brought researchers to consider users needs for the creation of Ubicomp applications. Especially, they stated the difficulty to conduct evaluations with large number of users due to the considerable technical work to be performed. This brought Scholtz and Consolvo to propose a framework to facilitate results’ sharing with other researchers [Scholtz et Consolvo, 2004]. Carter and Mancoff meanwhile discussed the use of summative and formative evaluations and the need for iterative designs to be adopted [Carter et Mankoff, 2004]. Following a user-centered design process, Davidoff et al.’s ethnographic study on device control in the domestic context also illustrated the gap between researchers’ focus and design principles that can be derived from field trips observations [Davidoff et al., 2006]. If these principles were acknowledged as difficult to embed into working systems, they constitute valuable insights for the design of user-centered systems.

From Edwards’ and Grinter’s point of view, the question of “designing the smartness” has a great impact on the architectural and implementation tradeoffs of technologies [Edwards et Grinter, 2001]. As more and more researchers were working towards the creation of proactive systems acting on behalf of humans, Rogers argued that technologies should be designed “not to do things for people but to engage them more actively in what they currently do” [Rogers, 2006]. She told us that users, designers and researchers should collaborate to address less ambitious challenges and try to “go beyond what is currently possible to do with our existing bricolage of tools and media”. The focus should be put on designing user experience supporting specific activities and contexts. To do so, she advised working towards small “ensembles or ecologies of resources that can be mobile or fixed” rather than complex context aware environments.

For industrial and interaction designers, connected objects capable of communicating with each other’s and delivering information and services constitute a tremendous but very difficult challenge. Hjelm recommended to “use the power of design to visualize and express” the complex issue of hiding computer technology and to develop the aesthetics of connected objects in “an organic relation to its own time” [Hjelm, 2001]. Norman’s information appliance model [Donald A. Norman, 1999], which aims at reducing the functional complexity of objects to deliver information or services through simple user interfaces, had a important impact before the rise of smart phones and touch interfaces. It demonstrated the need to design affordances reflecting the actual capabilities of objects. Another approach developed by Mavrommati and Kameas consisted in envisioning “hyper-objects” that work in synergy and “share their capabilities in a communal pool” [Mavrommati et Kameas, 2003]. Interconnected all together, all these objects therefore share the processing capabilities they individually have. If designers agreed on saying that objects’ form should be redesigned to communicate their new capabilities, they pointed out the inappropriateness of adding screens on every artifact. They instead claimed that conceptual models people have of objects would simply evolve with the use of new objects, whose redesign is nevertheless rarely addressed.

2.2. The role of design in Ubicomp research

By augmenting objects with information shadows allowing user to gain knowledge, instrumenting them with sensors generating data about their use or their immediate context and hacking them to allow the remote automation of their capabilities, Ubicomp researchers invented services that bridge the physical and digital worlds together. If these services are tied with objects, they nevertheless remained invisible to users who are generally forced to use a terminal to reveal the digital potentialities. A number of graphical user interfaces and interaction techniques [Rukzio et al., 2006] involving mobile phones equipped with cameras or Near Field Communication (NFC) modules have therefore been created to balance the lack of affordances of objects. If the need for transparent user interfaces and intelligible applications has been highlighted [A. K. Dey, 2009], bringing user interface designers and human computer interaction designers to investigate these issues, the opportunity to redesign the form of objects has rarely been explored.

This can be explained by researchers' concerns to provide a universal and easy-to-deploy solution (i.e. in most cases, mobile-mediations interactions are chosen to ensure the adoption of systems) and by the designers' lack of competencies, or interest, to experiment with embedded systems. Thanks to the democratization of easy-to-use prototyping platforms such as Arduino[4], designers are nevertheless today able to conduct their own research regarding the design of connected objects. Rapid prototyping methods combining cheap hardware pre-assembled boards, easy-to-program software and 3D-printed materials can be used to explore design concepts much more quickly than traditional engineering methods. These new possibilities lead product and service designers to strengthen their collaboration in order to considerate the service as an inseparable way of the product [Schneider, 2011] and to experiment forms and interactions with regards to these services.

As pointed out by Kuniasvky, designing connected objects not only requires the design of the physical object, its software interface and its hardware interface, but also of its interconnections with other objects and its virtual representation on the Web [Kuniavsky, 2010 18]. Instead of considering objects as independent artifacts, designers should work towards shaping the service delivery mechanisms that enable objects to work as ensembles [Encarnaçao et Kirste, 2005]. The way users can spontaneously articulate the services between objects and make them coax should be considered as an opportunity to enhance and shape the user experience. Places' scale, objects' ecosystem and population of course need to be considered in the design of this experience. It therefore implies "a shift in attitude to the process of design, to the sequence in which the experience is created, and to whom is involved at what stage" [Kuniavsky, 2010 46].

We propose to address that challenge from a practice-based research. The creation of design artifacts and their confrontation with users is indeed needed to leverage new or substantially improved insights. We argue that it is up to designers to leverage participatory and iterative design methods to generate and evaluate ideas regarding users' needs, services' cases, interaction techniques and objects' shapes. Such research cannot therefore be conducted without an exhaustive understanding of the technical possibilities offered by the Internet connectivity of objects. In the next parts, we especially focus on envisioning the opportunities and issues of using services as a design material and discuss the need to define a new design practice.

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[4] http://www.arduino.cc/

3. When objects meet the World Wide Web: novel capabilities and types of services

Since the original article of Weiser, Ubicomp researchers have conducted a lot of research on the development of scalable, flexible, reliable and robust networks of devices or sensors. This led a part of this community to especially focus on the creation of an Internet of Things [Bassi et al., 2008] and to picture the Internet as an extension of “a seamless fabric of classic networks and connected objects” whose impact will be intimately linked to the growth of the Web” [Hourcade et al., 2009 4]. The Web of Things approach [Guinard et al., 2011], which consists in exposing objects as accessible and addressable resources of the Web, substantially facilitates the creation of UbiComp applications. Popular Web technologies (e.g. HTML, Javascript, Ajax, PHP) can indeed be used to digitally enhance connected objects and allow them to communicate with existing Web resources [Boussard et al., 2011]. In this part, we present the capabilities brought by the Internet connectivity and the Web exposition of objects and the possibilities in terms of services.

3.1. Possibilities of connected objects

Thanks to embedded microcontrollers, web servers and connectivity chipsets, connected objects are capable of processing the same information than computers and to query data from existing Web resources. In the same way Web platforms are interoperating through dedicated programming interfaces (i.e. API), a vocabulary for resources or information requests can be created for objects. This allows objects and Web resources to communicate with each other’s and facilitate new types of interactions. Each of them can therefore be considered as a resource for the others and deliver content, share knowledge and shape behaviors. We describe these mechanisms, also illustrated on figure 2, in the following sub-sections.

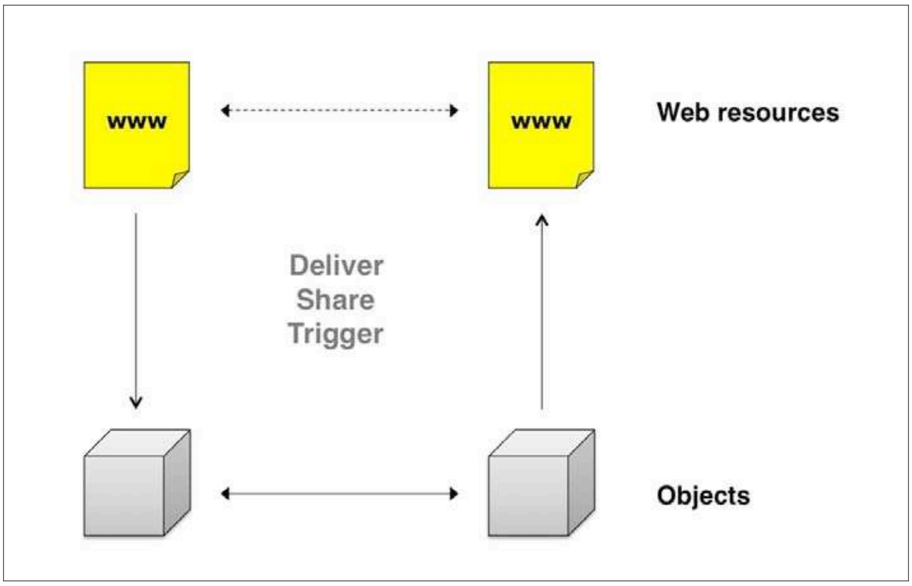

Figure 2. New capabilities of connected objects.

3.1.1. Deliver content

Some objects and Web resources are considered as media-related. They generate or convey the materials (e.g. text, picture, sound) that compose a document or a recording. In the physical world, this is typically the case of a radio, a television, a camera or a portable music player. In the digital world, user-generated content platforms such as Ubroadcast, Youtube, Flickr and Spotify[5] also aggregates content that can be communicated from a computer. A new capability of connected object consists in allowing such content to be delivered from the service to the object, depending on its user interface offering. This would allow an alarm clock to play streaming music instead of traditional FM/AM signals. Data can potentially be converted or reformatted in order to be compatible with a specific object (e.g. a text can be read if no display is available). In the same way, content produced or stored by an object can easily be sent or publish on a Web platform. Finally, as content can be shared from one platform to another, files could seamlessly be redirected from one object to another (e.g. projecting a presentation from a laptop computer without any video cable).

3.1.2. Share knowledge

A part from the content they are able to transmit, objects or Web resources are also capable of generating information that can be extracted, compiled or analyzed with regards to a user need or task. Objects can potentially provide data about their capabilities (i.e. what they can do), their statuses (i.e. how they are functioning at a given moment) or their use (i.e. How? When? By who?). On the other side, Web resources can bring value by obtaining specific information from multiple trusted sources that often require for a user to engage in a computing experience to be delivered. From an object perspective, connectedness allow for external knowledge to be communicated in a transparent way to ease users' life or augment their awareness. This would for example enable a digital photo frame to stress out unexpected event such as public transportations, traffic jams or weather issues by displaying widgets or alerts in the specific time of the morning. From a service perspective, objects can be used to gather very accurate information without user intervention (i.e. this is especially valuable for pollution sensing or goods tracking). Fine-grained statistics can also be published on a number of professional or social platforms to contribute to create shared representations of the real world or of people's activities and to better shape delivery mechanisms (e.g. suggesting Youtube videos based on users' television consumption).

3.1.3 Shape behavior

Objects are generally designed to respond to users' interactions. The manners in which they function therefore rely on human operations and can be easily predicted. Some of them, such as the washing machine or video recorders can be programmed. The inner working of Web platforms is slightly different: their API allows for other resources to control their features and compose them without any user intervention. In similar approach, the capability of connected objects to interoperate with other objects therefore makes several type of automation possible. Object to object interactions can be implemented to support domotic applications (e.g. setting up the heaters and shutters according to temperature and light sensors) and commands chained and be sent after a specific user's interaction with an object (e.g. automatically reducing the light intensity and declining calls when a user is turning his DVD player on). Web resources can also develop specific behaviors according to the information they receive from objects. Publishing rules can for example be implemented in order to avoid user-sensitive information to be broadcasted on social network platforms (e.g. posting a message on Facebook only when I lose weight). More importantly, Web resources can trigger the functions of objects with regards to the knowledge they acquired.

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[5] These Web resources can be considered as the digital equivalent of the mentioned objects.

3.2. Towards new services built with or for objects

Connected objects allow for new types of services to be instantiated on top of them. By seamlessly blending with artifacts, such services enable manufacturers and even end-users to customize objects with new content and augment them by shaping new behaviors from shared knowledge. We argue that different kind of services can be designed according to the capabilities they leverage. In this section, we present different used cased scenario motivated by examples in the literature that illustrate the potential of services aiming at aggregating objects' data, augmenting objects' capabilities and orchestrating an objects' ecosystem.

3.2.1. Computer or mobile-based services to aggregate objects' data

"Leila is a young woman really concerned about healthcare. She goes out running twice a week to keep in shape and like monitoring her effort and measuring her performances. The connected shoes se bought few years ago do a really good job, but she was also interested in meeting new people when she practices sports. That is why she subscribed to a service that helps her getting in touch with runners sharing the same profile. A part from allowing her to bond with people, this service also offers to monitor her weight and quality of sleep. By gathering data from her connected scale and by wearing a sensor bracelet at night, it provides Leila with comprehensive information about her daily life. All she has to do is to access the service on the laptop computer or to launch the dedicated mobile application. A few weeks ago, she paid for a premium feature that allows her to get advice from a personal coach, at a distance. She is also able to navigate through a social network of people using the same objects than her to compare their personal statistics or share comments, hints or reviews."

In this example, we illustrate the opportunity to extend existing Web resources to objects. Such services aim at facilitating the aggregation, the storage and the presentation of objects' states and uses. Designed for computer or mobile displays, they provide users with a comprehensible overview of a small or large-scale objects' ecosystem and make the creation of social networks of "things" or smart metering tools possible. If domains as energy consumption and life logging are most likely to be addressed in homes, such services can be used in the industry to track and manage assets. Delegation control of connected objects would then allow to remotely commanding them from a secured service.

3.2.2. Object-based services to augment objects' capabilities

"It is 7:30 am, Peter is woken by a song that has been randomly chosen from the music on demand platform he is subscribed to. His connected alarm clock postponed his waking after querying the local weather and traffic jam platforms. Due to the recent snowfalls that happened during the night, it would have been impossible to take the usual road and go to work without wasting several hours in traffic jams. As a precaution, all the meetings Peter was supposed to attend this morning have automatically been re-scheduled to later in the day. In accordance with his company's policy, he will work from home this morning. Peter is informed of the situation and presses the snooze button, triggering at the same time the publication of a micro-message on his favorite social network platform. He walks to his bathroom where the temperature has been perfectly set for his arrival. The house management service triggered the heater fifteen minutes before he woke up and has just sent a message to his coffee machine to be sure he will be having a lovely breakfast."

In this scenario, the service can no longer be considered as a traditional Web or mobile application, but as a set of new features specifically designed for a type or model of objects. Such services enhance objects' inner systems by enabling a new means of interoperability with other objects and Web resources and allowing users to customize their experience. They facilitate the circulation of content between objects and Web resources, offer to add a social aspect to objects by leveraging existing social networks mechanisms and provide users with the ability to shape a behavior based on open data or automate certain tasks or operations.

3.2.3. Environment-based services to orchestrate an objects' ecosystem

"Mike and Terry put a lot of effort into designing their home. They especially like decorating their living rooms with lamps and ambient displays such as digital photo frames and are looking towards shaping customized experiences. They create two services for their home that allows them to modify the ambiance of the room. As they watch a different movie every night, they like the mood to be changed automatically when their connected television is running a video on demand. Shutters, lights and speakers are adjusted without any intervention while their digital frames is turned off. Usually, the latter are displayed pictures taken from the social network accounts of people that are physically present in the room. Mike and Terry especially like this feature when friends are coming for dinner, it always start new discussions."

While in the last example services were augmenting objects, they here operate at a bigger scale. By involving multiple interconnections with objects, they allow to orchestrate users' environments. Objects' behaviors can therefore be preprogramed and triggered according to given contexts or events identified by the service. Data generated by objects can be used in conjunction with Web resources such as open data to define spatiotemporal situations or sense the presence of people. This makes automation of certain activity possible for inhabitants that could use assisted living systems or that are simply looking to save time. Content can also be delivered in a so-called "intelligent" way according to the social preferences or presence.

4. From the anticipation of issues to the identification of design implications

Tremendous possibilities are today offered to designers of connected objects. They are no longer required to define the number of delivered features but can potentially create open objects that can be charged with new services after being shipped to users. Objects can therefore be considered as open platforms which purposes are defined by people according to their needs or situations of use. This opens up the possibility for objects to be reconfigured and complemented, but also brings a number of issues that are likely to happen if designers do not consider the implications of new services on the design of objects. In this part, we discuss these issues and highlight the aspects that need to be taken into account in the creation of connected objects.

4.1. Pragmatic issues of connected objects

Many questions are left unanswered regarding the manner in which services, and especially the ones that augment objects or environments, orchestrate the life of objects, and by extension, ours. From a user-centered perspective, we propose in this section to anticipate, how users are likely to encounter issues related to the connectivity, dependency, setting and interoperability of connected objects. We argue that the lack of transparency regarding how objects allow users to interact with services, use personal data and share information constitute barriers to the adoption of connected objects.

4.1.1. Connectivity

Connected objects are provided with new access to services and seamless data circulation. However, do all objects need a continuous connection to the Internet and to the Web to deliver services and fulfill their functions? There is a growing concern about the consequences on health of electromagnetic waves emitted by wireless technology [Carvajal, 2007] and an uninterrupted connectivity will slow the adoption of this kind of objects. Some users already feel like they need to keep "free zones" where technology, considered as harmful or source of conflict, is less present or absent [Frohlich et Kraut, 2002]. This is especially true in homes where family members seek to separate personal and professional spheres. In addition to these social issues, we need to consider the environmental dimension. The over consumption of energy would nevertheless have less impact for electricity as it would be delivered in cost-efficient manner by "smart grids" [Mazza, 2002]. That is why problems of "online <> offline" management [Woodruff et al., 2007] and representation of the connection status should not only be addressed from a technological but also a social perspective. It is important that technology remains transparent when users either want to feel disconnected from the Internet or want to interact with the primary functions of their products.

4.1.2. Dependency

Once an object is augmented by services, it becomes more or less dependent on the infrastructure on which it relies. Bohn et Al. tell us that electronic books "appear to be more error-prone and less autonomous than normal books" because of their loss of autonomy [Bohn et al., 2005]. In general, appliances that surround us depend on an electrical infrastructure but at the same time can also be used independently of any other product. Allowing services to add features to objects and shape their behavior means there is a need to choose a "referent". In that case, which entity, from the embedded system or the service will control the other? The act of moving the entire intelligence of objects to the Web has many advantages (i.e. centralized data, absence of conflicts, apparent transparency) but in doing so risks altering the relationship that the user has with objects. The latter becomes an "empty shell" that merely executes the decisions taken more or less consciously by the user through a global life management service. The issue of control is even more crucial when a service rely on Web resources to shape the intelligence of objects. We argue that the balance must be found in the "master <> slave" relationship. It is important connected objects do not depend on their connectivity to fulfill their functions.

4.1.3. Settings

Because of their ability to process information, new objects can potentially deliver and interconnect with a multitude of services. Determined by manufacturers at the time of conception or by users after the purchase, their number and their nature are subject to change. Whatever the approach is, the issues surrounding the setting up of services seem inevitable. What kind of input methods will allow the user to provide the login and password required by the online services? Existing objects do not offer the proper user interfaces for alphanumerical entries. It would be indeed be very difficult to type text on a clock that has a small LCD screen using a limited number of unlabelled buttons. A synchronization phase (in situ or in a short perimeter) and the use of a suitable terminal are necessary. The use of intermediate artifacts (e.g. RFID tags) or recognition systems (e.g. finger prints, face, voice, DNA) that help the user to deal with authentication is possible, however, it adds complexity. Beyond issues of synchronization, associated service representation is also important for the transparency of experience. Will the user be able to make the difference between two objects configured with different services or should he leverage augmented reality systems? Since the perception of the object extension will affect its use, the notion of affordance [D. A Norman, 2002] is crucial.

4.1.4. Interoperability

New capabilities of connected objects make "object to object" interactions possible through the Web. Encarnaçao and Kirste tell us that future environments will be composed of smart ensembles sharing information to assist users with their tasks [Encarnaçao et Kirste, 2005]. Soon the artifacts will be able to use the semantic description of their functions [Boussard et al., 2011], to register their status, and a spontaneous creation of ecosystems will be possible. However, how will several interconnections or links between objects be made visible to the user? What level of control will the user have on the modeling of each object's behaviors? A system that does not integrate the user with the design of the intelligence can be understood as a form of manipulation or control. On the other hand, a "do-it-yourself" approach encouraging people to build their own ecosystem may require too much participation from the users. The interoperability issue described previously deals with connectivity, dependency and setting problems. Again, it seems crucial to give to the user every possible means to understand how objects operate together and how data flows circulate.

4.2. Design implications

By disseminating the technology in objects, we turn them into platforms supporting the instantiation of services. In doing so, we risk creating a gap between the perceived functions of objects and the role they are design to accomplish. It is therefore necessary to adapt the user interfaces of objects so that they can be widely adopted by the general public. We think there is a need for a transitional stage where intelligence is made visible, so that users have the feeling of living "with machines, not inside a machine" [Kaplan, 2009 201]. In this part we give greater consideration to objects that are used collectively and argue that a new means of control in the design of interactions and a shift in the manner smartness is considered are required.

4.2.1. Collective use

Most objects work without knowing the identity of users and deliver a generic user experience. Connected objects are nevertheless likely to deliver a customized experience (as computers do). Insofar as associated services aggregate personal data (preferences, history of actions, private information), objects inherited from existing appliances should be able to "understand" the context of their use so that they remain "user agnostic". People should be able to use their connected clock, as it is still an appliance, without having to login or state their identity. The identification methods chosen by manufacturers must be transparent, responsive and reliable. It is unlikely that people adopt products that require further actions to ensure the authentication, or whose execution time will be perceived as too long [Dearman et Pierce, 2008]. On the other hand, a weak security level may lead to misuse. In the same way that computer programs can reorganize themselves to better adapt to their environment, the concept of "behavioral reflexivity" would allow a connected object to suggest appropriate applications or reconfigure itself according to the circumstances. This can be achieved by embedding identification systems (e.g. cameras, fingerprints scanners) or rely on external devices such mobile phone or wearable RFID tags (e.g. bracelet, implants). All the data related to the use of object (i.e. how, where, when and by whom) and the understanding of the surrounding environment will then contribute to the creation of service delivery mechanisms and shape the object's intelligence. The way this information is shared within an ecosystem and used as inputs by services present major challenges for designers.

4.2.2. Control by the user

Norman tells us that objects should be designed according to the tasks they support [D. A Norman, 2002]. If users often have a limited understanding of the internal mechanisms of objects, the consequences of their manipulations are usually made visible by visual or audio feedback. The hybridization of the digital and the tangible allows new interactions between an object and services. Commands are executed by systems with the implicit consent of users and may affect the operation of applications or products, having consequences not only with the web, but also on reality. User interfaces should be adapted so they can inform, suggest and warn the users according to the situations of use. We argue that existing displays and input methods currently integrated into objects are not tailored for this. With the exception of touch terminals using graphic user interfaces, objects cannot rearrange their buttons or switches according to the type of services they offer. In order to facilitate the user adoption of connected objects, there is a need to materialize their capabilities and to give people new means of control over their data storage and sharing. Objects should not present an obstacle for the way in which people manage the boundaries between online, offline, personal and professional spheres. The design of new interfaces that could allow for the simple connection and disconnection to and from the Internet, activating and deactivating services or to swap data from one object to another could solve some of these practical problems and enhance the user experience. Especially connected objects that can potentially support a multitude of applications, related or not to the primary functions of the product. We argue that combining physical interfaces and virtual interfaces will address these problems and that it is up to designers to work on the organization and prioritization of proper interface layers that will reflect the potential of the digital sphere. Mixed reality technologies involving see-through head mounted displays and projected interfaces would allow visualizing and manipulating information in novel ways.

4.2.3. Task support

More fundamental questions regarding the way people's life revolve around tasks, and by extension objects, are underlined in the design of connected objects. By serving users and simplifying their daily life, automation, for example, also takes away many opportunities for experiences. Borgmann tells us that objects should not procure their commodities instantaneously but ask for attention and engagement [Borgmann, 1987]. Feelings of competence, autonomy, routine and familiarity play an in important role in the construction of pleasurable experiences [Green et Jordan, 2002] and by extension, happiness. We argue that objects should provide new services, but not deprive users of the experience they used to deliver. Connected objects can potentially be incredibly smart and fully automated, but they should let people touch, make or even hear the sounds they make. Instead of trying to work towards the creation of an ambient intelligence, we argue that designers should leverage the new capabilities of objects to allow users to reconfigure or repurpose them in a serendipitous way. Objects could then be used in multiple ways and under different circumstances to support users' tasks. This approach can be compared to the system design philosophy called "recombinant computing", which dictates that "computing environments can be created from the bottom up by creating individual entities to be part of an elastic, always changing whole." [Newman et al., 2002]. While some objects can be augmented by following a traditional approach, others can be designed for general purposes and serve multiple situations. Shape shifting technologies or materials, such as shape memory alloys or polymers, could hypothetically be integrated into objects to enable tangible reconfigurations of objects. This would allow shapes to reflect the content of services, and lead to the creation of a form grammar.

5. Towards a design strategy for reinventing objects and shaping service's experiences

In previous parts, we demonstrated that the augmentation of objects with new features brought by services has not only a great impact on users' relations with them but also on the way they interact with them. By adding smartness to objects, new behaviors can be shaped and triggered without any user intervention. This raises questions regarding the type of objects that should be augmented and the way they should be redesigned to reflect the possibilities of services. While the latter can constantly be recomposed or reconfigured, the form of objects is most likely to remain the same. The challenge is therefore to balance the physical constraints of materials with the limitless flexibility of information. Such question opens up for numerous design tracks to be explored. It also leads designers to consider the creation of new artifacts instead of envisioning the evolution of existing objects. Since people makes specific representations of what an object can do, trying to enhance existing objects may lead to misunderstanding and a slow adoption. Besides the issues of form, which are inseparable from interaction ones, the question of usage is also crucial. By turning objects into platforms of services, we offer people to define the features of objects by themselves. It is therefore needed to identify common needs that would be supported by the service offerings. The difficulty is now that services can deliver an experience that is no longer restricted to the scope of the object. Some interactions can happen in another room of the house or even in another part of the city. In the following sections, we present the first elements of the design strategy that is currently developed at Bell Labs. After presenting the context of our work, we discuss the ongoing research conducted on the design of tools and experiments that allow us to explore the futures of connected objects, investigate users' mental models, identify needs and shape new user experiences.

5.1. Context of work

Within Bell Labs Applications domain, highly technical components are being developed by a team of engineers with a strong Ubicomp background to enable the creation of connected objects and services. Driven by the Web of Things approach, this research especially aims at modeling objects' representations, architecting objects' gateways, and creating service models. A part from semantic descriptions of objects' capabilities, service deployment mechanisms and access control systems, navigation tools and connected objects have been designed to illustrate the potential use of the overall infrastructure in domestic, corporate or urban contexts. In order to ensure the user adoption of such technologies, three members of Application Studio (i.e. Bell Labs user-centered multidisciplinary department) stepped into that research project: an interaction designer, a product designer and a usabilist/psychologist. In this context, we aim at developing a design practice where multiple disciplines intervene at different steps of the projects. By placing users at the center of our research, we work towards the creation and the evaluation of tools designed to provide us with insights regarding users' perception, needs and acceptance of connected objects. This joint-collaboration with technical researchers led us to identify three research tracks that compose our design strategy.

5.2. Envisioning multiple futures of objects

Observing market trends, companies' prospective vision of technologies (i.e. often communicated as videos illustrating innovative interactions or services in various use case scenarios) and artifacts produced by the research community is a first step in the understanding the context. An exhaustive collection of pictures and its organization in boards allowed us to picture the current state of the market and to identify the current evolutions of objects, as illustrated on figure 1 and 4. This led us to envision different futures involving different type of modifications regarding the design of objects and explore few of them, as described in the following sub-sections.

5.2.1 Insights

Our analysis of the state of the art showed that objects can whether:

– **remain the same and need a terminal**. Most researchers and manufacturers of connected objects currently adopt this approach. Mobile or computer mediations are leveraged to allow users to configure or interact with the capabilities that cannot be accessed from the physical user interfaces.

– **become docks for terminals.** By making technologies converging into one device, smart phones have already replaced many objects. Alarm clocks, radios or music players are not as popular as before. This leads manufacturers to redesign such objects as docks that are used in combination with terminals.

– **become a touch interface.** The success of touch interactions leads the industry to integrate touch screens into objects' form factors. This tends to reduce the place of physical user interfaces to the benefit of graphical user interfaces that can be refreshed with a single tap.

– **disappear in the environment.** With the ongoing research conducted on flexible and very thin displays that can be embedded into walls or windows, companies illustrate a future where information and services are delivered by the environment. This would bring people to own and use fewer objects than today and interact with services through multiple surfaces.

– **be redesigned with physical and virtual users interfaces**. Concept products as the Olinda radio[6] demonstrate that services instantiated on top of objects can be materialized with dedicated buttons, displays or interactors. As mentioned in part 4, projected or mixed reality interfaces can be used to avoid overloading the physical user interface.

– **explode in several modules.** Researchers of tangible computing have already explored the concept of graspable building blocks that can be combined to produce (e.g. especially in tangible programming) or interact with systems. Such approach can be adopted to create modules for each core feature of a given object.

– **be reinvented to allow shape shifting.** A more prospective vision consists in picturing objects as dynamic entities capable of changing their forms according to the context of use or to the associated services. This approach can be considered as the most disruptive since it does not follow any pre-established standards regarding the shape of objects.

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[6] A radio augmented with a social network designed by Berg. http://www.berglondon.com/projects/olinda/

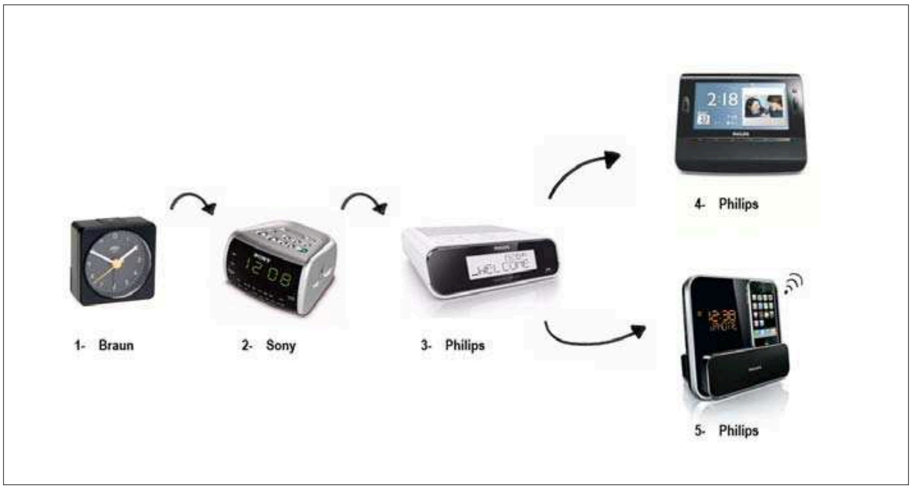

Figure 3. The evolution of an alarm clock.

5.2.2 Exploring the visions with users

From the described approaches, we consider the last three are as the most interesting for research. While the first three undergo a strong influence of smart phones, changing the natural qualities of objects, the others aims at creating artifacts that maintain their role in users' life and environments. In order to investigate the interaction design and product design dimensions of connected objects, we have conducted several projects described as followed:

– **a workshop with design students.** We asked a group of twenty-one fourth-year students in interaction design and spatial design to study the usage of an object and to explore its futures. They had five days to come up with new features and services that augment its capabilities, and to work on a complete re-design based on the selected approaches. They were especially asked to illustrate the gestural language allowing users to interact with these new capabilities. This initiative showed that students had difficulties to project themselves in a world where the role of objects is reinforced by services leveraging existing Web resources. As such objects are likely to compete with computers and mobiles that can do more, and "better", they instead focused on adding smartness to "dumb" things or creating tangible interfaces. If deriving from a mono-functional object to create new services can be considered as easier, we argue that students could not really complete the exercise because of a lack of meaningful objects' augmentations and pre-established mental models (i.e. we discuss these issues in the next section). Time constraints certainly also had an impact on students' productions.

– **a participatory design session with intermediary artifacts.** A different methodology has been developed with a group of six people (i.e. researchers or interns with a design or usability background) in order to explore the potential of shape shifting objects. Participants were given six mockups allowing different types of manipulations (e.g. inflatable, combinable, retractable, rotatable, foldable, etc.) for short periods of ten minutes. They had to come up with any kind of ideas related to the type of services that could be communicated by such moving shapes. Proposals were written on sticky notes and discussed by the group. Each of them has been categorized and subjectively evaluated. Ideas considered as most relevant in the context of connected objects have been illustrated as shown on figure 4. This session unexpectedly produced more insights regarding the way people would like to manipulate such open-ended shapes than concrete service cases scenarios. While functions remains undefined or fuzzy (e.g. sending a message to friends, accessing the news, playing music, etc.), some users had a clear view on the type of interactions they could performs according to the different artifacts. We argue that such intermediary representations facilitate the projection of users in a specific future of objects and could be used to support sessions on usage exploration.

– a case study of the alarm clock. We decided to experience the same approach than the one developed during the student workshop in a much longer period. An interaction designer and a product designer chose to explore the different futures of the alarm clock. We picked this object for its collective dimension and its role regarding the preparation of the day. After conducting short interviews with users and non-users of alarm clocks in order to gather insights about its actual use, we managed to identify opportunities to enhance their capabilities (e.g. especially in the way the alarm is set up or awake people) and add new ones (e.g. supporting users in their morning tasks). Three concepts have been developed from the different approaches (i.e. materializing services, creating modules, allowing shape shifting). Each of them results from complex trade-offs between form, function and interaction and led us to diverge from the original alarm clock. We argue that this methodology forced us to consider services as a design material of objects, and to reason in terms of tasks that go beyond the pre-existing mental models of what an object can do. We look towards to prototyping theses concepts in order to confront them with users in real life situations or participatory design sessions. We are interested in evaluating their value as objects and creation tools.

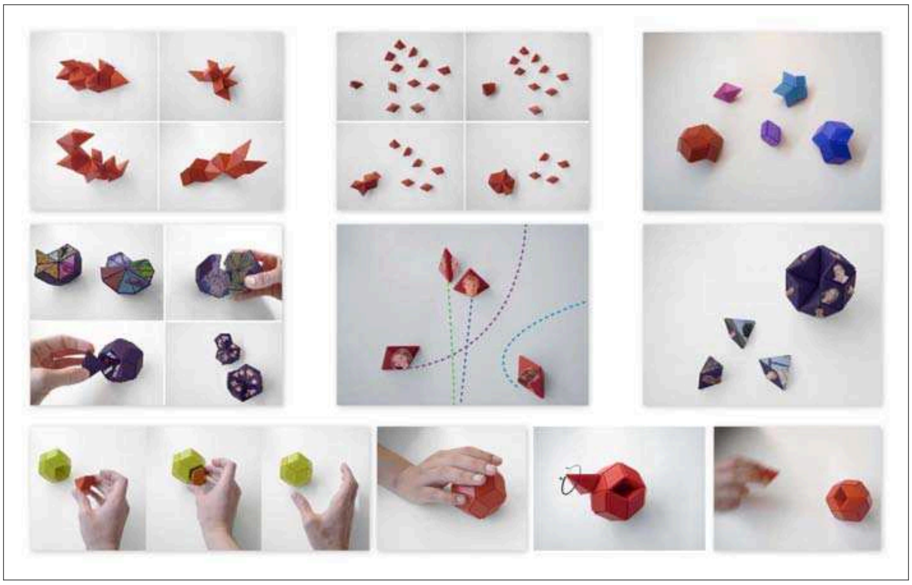

Figure 4. Interactions or service cases generated during a participatory design session.

5.3. Changing established mental models

People make their own representations of everyday things, called mental models, in order to interact with the world. Defined by Rouse et al. as “mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states” [Rouse et Morris, 1986 351], these models evolve naturally through interactions with systems and are therefore affected by users’ prior knowledge and experiences [Donald A Norman et Draper, 1986 45]. As mentioned in previous part, these preexisting representations are likely to be impacted in the use of connected objects whose capabilities have been augmented and whose inner working is more difficult to apprehend. If mental models are subject to change, it is needed that designers investigate the way people perceive the interconnections between objects and services in order to ensure the intelligibility of the overall system. In the following, we present an experiment aiming at capturing user's mental models of an objects' ecosystem and discuss some insights.

5.3.1 Investigating mental models with users

As connected objects have not yet been introduced in users' life (i.e. except from Nabaztags, so-called smart meters, televisions or radios have not hit the French market yet), we built a protocol allowing participants to project themselves in a simulated reality involving well-known objects and services. By asking them to draw a schematic representation of a non-existing but functioning objects' ecosystem (i.e. depicted in a provided use case scenario very similar to the ones proposed in sub-sections 3.2.2 and 3.2.3), we tried to extract their mental models. Since people generally do not develop the same mental model of a system [Payne, 2003], we focused on measuring users' understanding of the different representations or schemas with a questionnaire. During this qualitative evaluation, we introduced an anonymous schema designed by our team (i.e. illustrated on figure 5) in order to get feedback from users. Interviews were also conducted in order to gather more insights and better understand users' representations. After the experiment, we finally tried to make connections between the schemas in order to identify patterns or remarkable strategies.

This 45-minutes experiment has been iterated two times with groups of 6 design students from different schools and with different background (i.e. the first panel was mainly composed of product designers interested in the design of connected objects while the second was mixing interaction, spatial and product designers with no specific affinity with the domain). Twelve drawings representing a system of height objects (e.g. an alarm clock, lamps, shutters, mail box, heater, coffee machine, photo frame) leveraging information or knowledge from Web resources (e.g. several social networks, music on demand platforms, online agenda, traffic jams platform, etc.) were produced. Besides our interest in knowing which drawings were best perceived by participants, we were concerned by the validity of the overall concept of object-based services and environment-based services.

A grid, which incorporate our research questions, was finally created to interpret the productions with regards to the:

– **understanding of object-based and environment-based services.** Are services represented? Can we count them? How many relates to an object? How many relates to the environment?

– **strategies of categorization.** Are objects and Web resources organized in clusters? Can we count them? Are they labeled?

– **type of interconnections between objects**. How are links directed? How many different types can we count? Are they captioned?

– **representation and application logic.** Does the schema follow a specific structure? Is the logic of the service represented? How?

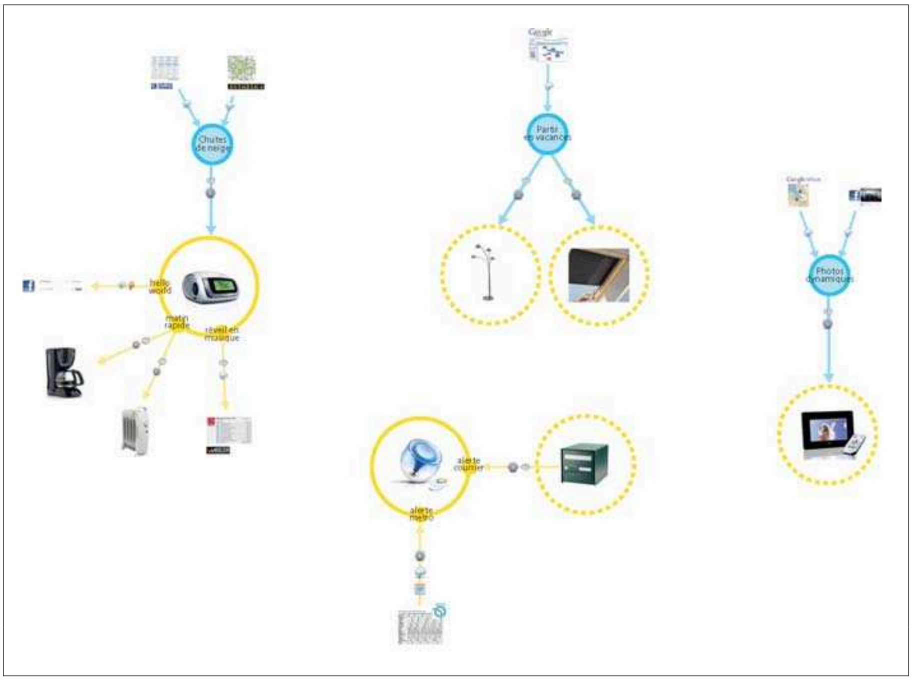

Figure 5. A refined version of the objects' ecosystem designed by our team.

5.3.2 Insights

Surprisingly, this exercise has been considered as difficult by most of the participants. Many of them had trouble envisioning a world where connected objects are able to process information an services. This is reflected by the different strategies adopted by users to represent the ecosystem. While the clearest drawings can be compared to network maps where objects and Web resources are indifferently represented as nodes, others use alternative metaphors, as shown on figure 6. For example, users created personal timelines showing a sequence of tasks, as well as representations where objects revolve around a "computer brain" or an "internet bubble" making the link between the physical and digital worlds. If users did not use the terms object-based and environment-based services, the way they grouped objects and labeled some of them indicates that such concepts are underlying in their representations. This analysis validates the taxonomy described in section 3.2 and brought us to argue that designers and researchers need to:

– **Explain the different type of services.** Computer-based, object-based and environment-based services involve different mechanisms and interconnections. Each of them should be communicated in a way that allows users to clearly distinguish and understand them. This therefore requires a learning phase where people are introduced to the capabilities of services.

– **Considerate object-based services as single features**. If objects can be considered as platforms of services, the model of multiple services clustering lots of different features does not seem to make sense for users. In most cases, participants appear to consider object-based services as a range of simple augmentations leveraging the functional DNA or the user interfaces of objects. This would require avoiding creating complex services that combines too many Web resources and propose another term.

– **Enable reallocation of services.** Results of the experiment showed that people sometime arbitrarily distribute the intelligence as they see it. While some users may considerate some objects as querying another, others can see the latter as controlling the first one. Representations provided by designers should therefore be flexible enough to allow users to move a service from an object to another in order to make the system fit their own mental models.

– **Design multi-scale representation modes.** We learned that users do not always care about the functional logic of services. If a graphic language would make some parts of the inner working of applications visible and allow people to change parameters, exposing the full logic of services would cause an information overload. That is why visualizing tools allowing users to "zoom" in their objects' ecosystem and switch from global views to detailed representations are required.

We argue that such insights about users' mental models are required to properly design connected objects and services. Since services constitute a new design material, it is need to understand how users perceive them as part of an object or the environment. By collecting such observations, we aim at driving the creation of systems that supports users' models and are therefore easier to understand and to use. In future work, we plan to re-conduct this experiment with different panels to validate our findings and confront users with real connected objects. We are interested in observing how mental models can evolve and what kind of tools or artifacts can support this change.

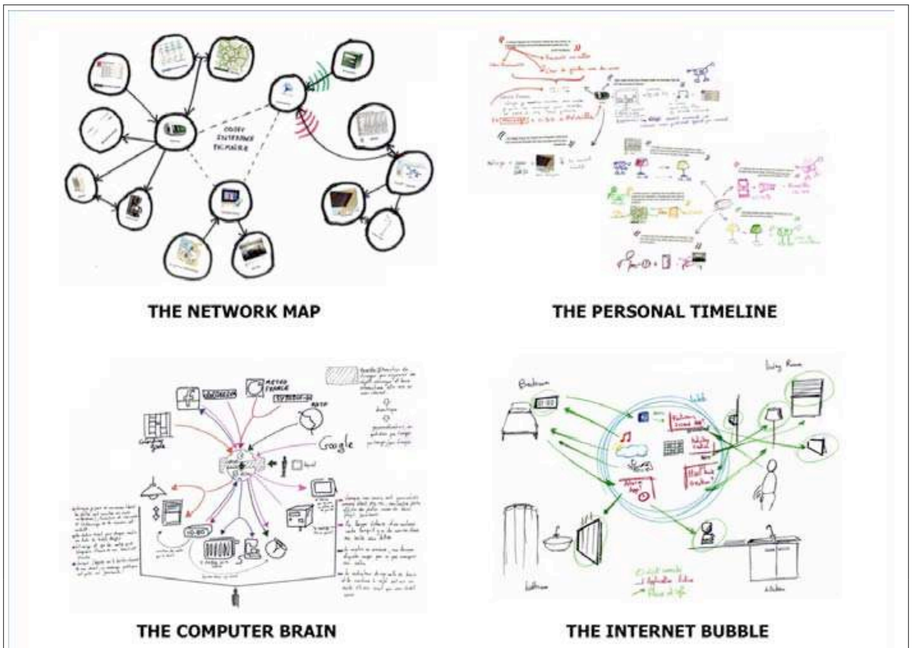

Figure 6. Different user-defined metaphors of the same objects' ecosystem.

5.4. Supporting latent needs

Besides goods tracking, energy consumption and assisted living matters (i.e. often discussed in European projects such as SENSEI [Wilson et al., 2009]), researchers and experts seem to have difficulty finding Ubicomp applications involving domestic objects. Leveraging Web resources to create new services delivered by objects opens up for numerous possibilities, but do not revolutionize people's life. Looking for disruptive innovations, researchers usually depict use case scenarios that often suffer from a comparison with computers and smart phones applications, considered as easier to deploy or sometimes use. For Weiser, Ubiquitous computing enables “nothing fundamentally new, but by making everything faster and easier to do, with less strain and mental gymnastics, will transform what is apparently possible.” [Weiser, 1995]. Web tablets such as Apple iPad resonate with the vision of Weiser and especially the Parc Pad device. While tablets did not offer more features than laptop computers (i.e. on the contrary, the iPad did not initially supported multitask and still not offer to play Flash animations), they can be grabbed and used anywhere. One of the strong aspects of Ubicomp is to mitigate the importance of traditional computers, it makes computing immediate, trivial and easy to use. We do not need to connect objects to the Internet per se, we simply have the opportunity to access information and interact with Web resources differently, in more natural ways. It is therefore up to designers to investigate users daily life and identify what tasks or situations can be better supported.

5.4.1. Generating service cases with users

We conducted two studies at the beginning of our research project, which illustrate the lacks of existing methodologies applied to the Ubicomp domain. They were conducted with the same panel than the one who participated in the mental models investigation and aimed at:

– **identifying potential objects to be augmented with a contextual investigation.** The six fourth-year students agreed to participate in a study about their objects’ use. On a daily basis, they had to fill out a diary with a list of all objects they interacted with (i.e. the following categories where created: at home, at school, in public transportations as illustrated on figure 8). Ten pages corresponding to ten consecutive days where proposed in the booklet, which was also composed of another section inviting people to select five of their favorite objects. For each of them, they had to answer questions about their use (i.e. what do they do with it) and the motivations that led us to buy them. They also had to provide information about their degree of collectiveness (i.e. personal, used by few member of the family or shared with many different people), their mobility (i.e. fixed, sometimes moved, brought outside the home) and their perception (i.e. functional, aesthetical and affective values). They finally were asked to describe the features that can be performed by each object and to compare them with ideas of new capabilities.

– **combining objects and Web resources during a participatory design session.** We asked the panel to create service cases involving connected objects. In order to facilitate the creation process, we provided them with cards representing daily life objects (e.g. television, photo frame, camera, washing machine, fridge, hair dryer, etc.) and Web resources (e.g. social network news feed or messages, metro timetable, cultural agendas, traffic or air quality information, etc.). They had one hour to come up with combinations that would benefit someone and to fill out a “service card” for each of their ideas. Describing the way objects and Web resources operate and the added value of this composition, these cards were shared with other participants at the end of the session and evaluated with sticky notes. Each student could only vote for the three cases that he found the most interesting. Figure 8 shows a picture of the session.

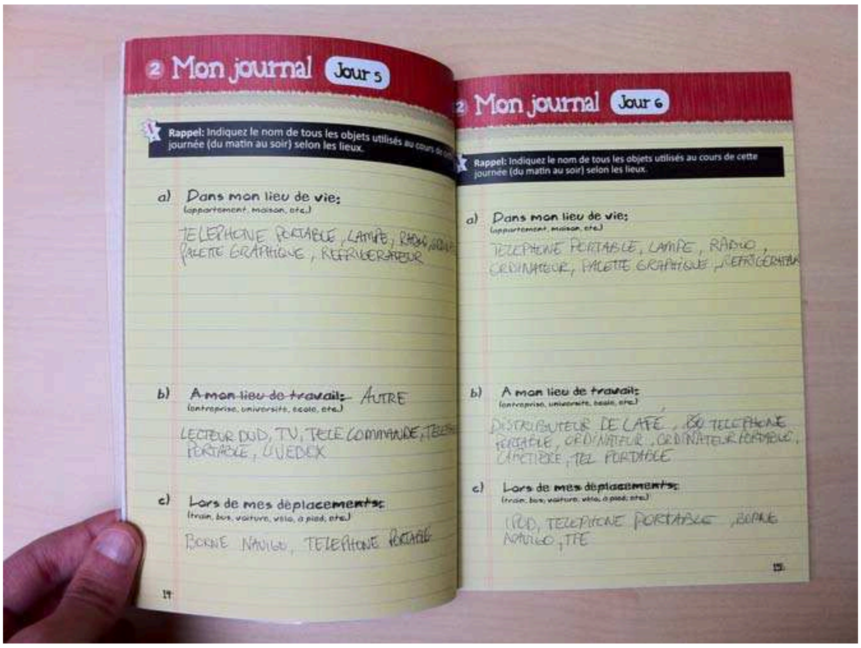

Figure 7. Two pages of the diary used by participants to report their objects' use.

5.4.2 Insights

These studies produced unexpected insights. While we were looking towards ideas of objects to augment and new services to instantiate on objects, we found out that users could not project themselves in the future or predict the long-term value of connected objects.

The contextual investigation confirmed the dominant use of computers and smart phones, which were picked by every participant, and the reduced number of objects possessed by students, whose temporary lodging and relatively low income do not allow for much variety. Users had globally very few ideas on how to augment their most-preferred or used objects, maybe due to a low motivation and a lack of incentive. If structured diaries are easier to fill out for participants, they require investing a precious time. We might have improved the number and quality of contributions by using sampling methods, which consist in asking participants to answer questions on specific signals (e.g. a text message or e-mail). As mentioned before, participants did not clearly see the opportunity to enhance objects with Web resources but mentioned general problems that they encounter in objects' use.

The participatory design session generated around thirty concepts of object-based services. While interesting ideas related to alternative ways to communicate information through ambient displays or lights, most of them suggested functionalities that were already provided by existing terminals or relayed in science fiction movies. This reveals the difficulty for participants to evaluate a concept. One that sounds uninteresting might be considered as indispensable when experienced, while another that seems exciting can be disappointing afterwards. Many service cases were especially inspired from dreamt visions of the automated homes. This indicates the influence of what people know in their creation process. When interviewing Rafi Haldjian[7], Kuniavsky learned that focus groups conducted during the

[7] Former CEO of Violet, the company that designed the Nabaztag.

development of the Nabaztag to brainstorm potential uses for the connected rabbit did not brought valuable insights [Kuniavsky, 2010 248]. We argue that it is therefore needed to explore alternative research methods that would allow users to experience few services with specifically designed interactions. In future work, we plan to investigate the creation of intermediary objects and probes.

Figure 7. A participatory design session aiming at generating service cases.

6. Conclusion

In this article, we addressed the research domain of Ubiquitous Computing from a design perspective. We stipulated that advances in technology, changing practices and market trends made possible the realization of a world were computational capabilities are disseminated in everyday objects. The extension of the Internet to physical artifacts today represents a logical evolution for manufacturers whose products are challenged by the digital convergence of medias and telecommunications. This context brought the research community to shift from a technology-driven approach to a user-driven one. If not all technical barriers have been lifted, it is now possible to leverage Web of Things architectures and electronic platforms embedding Web servers to easily create services mixing objects with Web resources.

This led designers to step in and to collaborate with engineers to focus on the design of user experiences and to acknowledge the need to explore the implications of using services as a core component of objects. The use of information as design material opened up the possibilities for objects to share content delivery mechanisms, knowledge and behaviors with other objects, but also existing Web resources. Such capabilities allow for new types of services that monitor, augment or orchestrate objects to be created. We argued that each of them revolve around a different medium, respectively a computer platform, a physical artifact and an environment. We then demonstrated that a number of issues regarding the connectivity, dependency, settings and interoperability of connected objects could be anticipated from basic use case scenarios. This led us to identify and discuss the need of considering the collective dimension of objects, as well as the means of control given to users and the way services supports their daily tasks.

In the final part of the article, we discussed the methods and tools developed or adopted to address three main research tracks on the exploration of possible future of objects, the capture of users' mental models and the production of use case scenarios involving objects and services. A literature review and a benchmark of existing connected objects brought us to work toward the redesign and the reinvention of objects as functional modules that can be composed and shape-shifting entities defined by services. We argued that making services more visible would free users from the mobile mediated interactions that are often leveraged. We then presented the first results of an experiment aiming at better understanding the perception of connected objects' ecosystems by users. We finally discussed the low utility of conducting diary-based contextual investigations and participatory design sessions in the identification and creation of new concepts of services.

The first findings of these ongoing experiments today allow us to work towards a user-centered design strategy. If researchers should keep exploring the outcome of Ubicomp and its applications, we argue that it belongs to designers to contribute to the research community by:

- exploring the possibilities and issues of using services as a design material
- studying the impact of services on objects' shape, interaction and relations
- defining services models that matches the mental models of users
- developing tools that allow to investigate, validate and create with users

As pointed out by Kuniavsky, there is a need to design "multi-scale user experiences" where digitally mediated activities move between scales and involve the participations of users at different scales [Kuniavsky, 2010 174]. The major challenge of Ubicomp is to maintain a perceived continuity of experiences and we hope to contribute to both design and computer science communities by working towards a better definition of such practice.

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